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THE WATER FOOTPRINT OF THE SPANISH AGRICULTURAL SECTOR: 1860-2010

Rosa Duarte*

Vicente Pinilla**

Ana Serrano*

*Universidad de Zaragoza, Departamento de Análisis Económico, Facultad de Economía y Empresa. Gran Vía 2, 50005 Zaragoza, España, rduarte@unizar.es, asergon@unizar.es

**Universidad de Zaragoza, Departamento de Economía Aplicada e Historia económica, Facultad de Economía y Empresa. Gran Vía 2, 50005 Zaragoza, España, vpinilla@unizar.es

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Resumen: Desde 1860, el sector agrario español ha experimentado un intenso proceso de desarrollo, que ha implicado importantes cambios estructurales, tanto en el propio sector como en la relación de éste con el medio natural. Estos cambios han estado fuertemente ligados a la creciente renta per cápita, a la fuerte integración comercial y a profundas transformaciones políticas. Durante los últimos 150 años, la producción agraria española ha crecido fuertemente, lo cual ha generado un creciente consumo de recursos hídricos y ha hecho necesaria la construcción de infraestructuras hidráulicas, claves para el desarrollo el regadío. En este contexto, este trabajo estudia la evolución del consumo doméstico de agua como resultado del crecimiento de la producción agraria, así como el impacto que las crecientes necesidades de agua han tenido sobre la construcción de infraestructuras para regadío. Con este objetivo, se estima la huella hídrica de la agricultura española, esto es, se trata de obtener el agua consumida para producir productos animales y vegetales en cinco periodos: 1860, 1900, 1930, 1962 y 2010. Una vez calculada el agua incorporada en la agricultura española, se lleva a cabo un estudio de las principales tendencias y cambios composicionales del consumo de agua. A partir de la información existente sobre la construcción de infraestructuras de regadío, se examina en qué medida el desarrollo del sector agrario condicionó la construcción de nuevas infraestructuras. Finalmente, se aplica un análisis de descomposición (DA) que permite identificar y cuantificar los factores explicativos de la senda seguida por el consumo de agua agrario en el largo plazo.

Palabras clave: producción agraria, huella hídrica, regadío, análisis de descomposición

Abstract: From 1860 the Spanish agricultural sector has gone through an intensive process of development resulting in important structural changes, not only in the sector itself, but also regarding the relationship of the agrarian system with natural resources. These changes were closely related to the growing per capita income in the long term, an increasing degree of integration in international markets and profound political changes. During the last 150 years, the volume of Spanish agricultural production experienced a great increase, notably affecting the consumption of domestic water resources and entailing the need for the construction of waterworks, key for the development of irrigation. In this context, this paper studies the evolution of domestic water consumption as a consequence of the increasing agricultural production, as well as the impact that the growing needs for water had on the construction of infrastructure for irrigation. To that aim, we estimate the water footprint of the Spanish agricultural sector, that is, we will try to obtain the water consumed in the production of vegetal and animal goods for five different years: 1860, 1900, 1930, 1962 and 2010. From these results, a detailed analysis of the trends on water consumption and changes in compositional patterns is carried out. Moreover, we collect the available information on the building of new irrigation infrastructure to examine to what extent the development of the agricultural sector conditioned the construction of new irrigation infrastructure. Finally, a Decomposition Analysis (DA) is applied to analytically identify and quantify the main explaining factors behind the evolution followed by the increase in agricultural water consumption in the long term.

Keywords: agricultural production, water footprint, irrigation, decomposition analysis

JEL Codes: N53, N54, Q10, Q25

1. Introduction

Modern economic growth and the changes associated with it (income and population growth, urbanization or structural change) profoundly modified the relationship of economies with natural resources. On the one hand, the energy transition, with the use of coal first and oil after, multiplied the productivity of economic activities. In this context, mechanization was crucial for the development of industrialization (Allen, 2009; Wrigley, 1988; Stern, 2011; Stern and Kander, 2012). On the other hand, the intense growth has generated severe impacts on the environment. An extensive literature has addressed these impacts from a long term perspective. The main topics have been the energy transition (Gales et al., 2007; Kander and Lindmark, 2004;Rubio, 2005), the atmospheric pollution (McNeill, 2000; Krausmann et al., 2008; Stern, 2005; Stern and Kaufmann, 1996), forest resources (Iriarte-Goñi and Ayuda, 2008 and 2012), the effects of land use on ecological biomass flows (Krausmann et al., 2012; Kastner, 2009; Kohlheb and Krausmann, 2009; Krausmann, 2001; Musel, 2009; Schwarzlmüller, 2009) or materials use (Krausmann et al., 2009). This significant process of parallel economic and environmental transformations has been conceptualized as a change in the social metabolism of economies (Fischer-Kowalski and Haberl, 1993; Krausmann, 2001; Krausmann and Haberl, 2002; Krausmann et al., 2003).

Use and consumption of water, has also been seriously influenced by modern economic growth (Duarte et al., 2013 and 2014a). In fact, the scarce historical data available seem to point at huge increases in water withdrawal from the XIX century. McNeill (2000) indicates that in 2000 water use was sixteen times higher than in 1800 and according to L'Vovich and White (1990) while global water withdrawals remained stable for centuries, these increased thirty-five-fold from 1687 to 1987. The use of water has grown principally because of the formidable expansion of agriculture experienced in the last two centuries that allowed achieving food security for large populations but also meant the use of more land as well as the need to undertake important waterworks for the extension of irrigation in arid or semi-arid regions. Worldwide irrigation involves over 18% of cultivated land and provides between 30% and 40% of gross agricultural production; figures that tend to be higher in arid and semi-arid regions (Federico, 2005). Irrigation has been utilized, especially in arid countries, as a way to substantially increase agricultural production, to ensure its regularity and allow land use changes. Recent estimates for the case of Europe during the second half of the XX century show a significant influence on the increase in labour and total factor productivity (Martín-Retortillo and Pinilla, 2012 and 2013).

Some studies have addressed the impact that the agricultural development had on the human appropriation of biomass on the long term. (Krausmann et al. 2012; Fetzel et al., 2014; Haberl et al. 2012; Kohlleb and Krausmann, 2009; Erb et al., 2009; Musel, 2009).However, the effect of these processes on water resources has not been tackled from a historical perspective.

In this context, the objective of this article is to analyse the effect of the expansion of the agricultural sector and the consequences of its developmenton water consumption. Especially, we would like to assess the impact of the growing requirements for water in semiarid and developed countries on the need to construct infrastructure for irrigation during the long term period from the mid-XIX century to today.

To that aim, we use Spain as a case study. Spain, as a semiarid developed country that went through a long term process of industrialization, has also increased its water withdrawals affecting its landscape. Agriculture went from being the most representative sector in the Spanish economic structure in the XIX century and the beginning of the XX century to be negligible nowadays. In fact, according to Prados de la Escosura (2003) agriculture represented 39.2% of GDP and 63.5% of employment in the period 1855-1866. It slightly decreased by 1901-1913 being 31% of GDP and 58.7% of employment and fell down in the period 1992-2000 accounting for 4.5% of GDP and 7.8% of employment. However, its impact concerning the use of natural resources is notable. In this regard, Spain stands out along the XX century as the second country in the ranking of harvested land in the European continent, excluding the former Soviet Union republics (Martín-Retortillo and Pinilla, 2012: table 2). Currently, despite irrigation occupies only 13% of this area, it involves more than 50% of final production, producing on average six-fold greater than a rainfed hectare of land and an income four times higher. Moreover, nowadays irrigation is the main user of water entailing 68% of total water withdrawal (MAGRAMA, 2013).

The development of agricultural production in Spain between 1850 and 2000, the causes of its growth and the characteristics of its transformation have been widely studied by economic historians (GEHR, 1983; Garrabou and Sanz, 1985; Jiménez Blanco, 1986; Barciela and García, 1986; Simpson, 1995; Gallego, 2001; Clar and Pinilla, 2009; Clar, 2008). Similarly, literature has also studied the long term environmental impacts of this agricultural growth process during the last years (González de Molina, 2002; Cussó et al., 2006a and 2006b; Marull et al., 2008; GuzmánCasado and González de Molina, 2006; Infante-Amate, 2102a and 2012b; Infante-Amate and González de Molina, 2013; Infante-Amate et al., 2013; Schwarzlmüller, 2009; Tello and Ostos, 2011; González de Molina, 2010; Carpintero and Naredo, 2006).

Irrigation has also traditionally attracted attention of many researchers, although the emphasis was on the development of hydraulic works and the administration and management of water (Fernández-Clemente, 2000; Herranz, 2004; Gil-Olcina and Morales-Gil, 1992; Barciela and López, 2000). The study of irrigation agriculture in the long term has also been widely analyzed, particularly from a regional and basin perspective (Garrabou and Naredo, 1999; Pinilla, 2008).

The period considered is crucial for the study of water in Spain, a semi-arid country with significant cyclical water shortages. Thus, it begins in 1860, when the agricultural production in Spain was expanding as a result of both domestic and foreign demand, which grew due to the integration process of Spanish agriculture in international markets. During the XX century the sector experienced important changes associated with technological development. The Civil war and the autarkic policy carried out during the first decades of Franco's dictatorship; put a halt to this process, which would be resumed by the mid-fifties. From this moment an intense modernization process associated with production and productivity growth took place, entailing the end of traditional agriculture in Spain. Moreover, technical advances from the beginning of the XX century allowed constructing hydraulic infrastructures that went from being paid by private investors to be mostly funded by the government. The development of irrigation was essential to set up an intensive agriculture with a marked exporting character.

To go further into these issues we will obtain the water embodied in Spanish production, using water intensities from Mekonnen and Hoekstra (2011, 2012) and agricultural production data from "Anuario Estadístico de la Producción Agraria" (MAGRAMA, 1929-2010). First introduced by Allan (1993), virtual water is defined as the volume of water required for the production of a commodity. Many current studies on water resources focus on agricultural and food products since, as in the case of Spain, the production of these commodities is the main water user in many regions(Chapagain and Hoekstra, 2011; Hoekstra and Mekonnen,2012).Thus, following the bottom-up approach proposed by Hoekstra and Hung (2005), we obtain the virtual water embodied on Spanish production, studying not only its trajectory in the long run, but also the possible changes on its composition. We analyse both green water -rainwater evaporated as a result of the production of a commodity- and blue water -surface or groundwater evaporated during a production process- (Hoekstra et. al, 2011). Although they are interrelated in the hydrological system, the features and implications of using each colour of water are quite different. On the one hand, blue water is said to have higher opportunity costs than green water, given that it can be reallocated among the different users, while green water cannot be easily reallocated (Yang et. al., 2007). Furthermore, the increase in the use of blue water has great economic implications, since it demands considerable investments of capital, both public and private.

Moreover, in this paper we obtain and calculate the contribution of the factors that may lie behind the changes in the volume of water embodied in production. To that aim, a Decomposition Analysis is applied for each period, identifying and estimating the effect that changes in the volume of production, variations in its composition and yield improvements had in the embodied water in Spanish production. In this line, it is important to highlight that this study considers variable and time dependent water intensities. As explained in the data section, constant water intensities have been traced back to the past, considering long term changes in crop and livestock yields.

Eventually, we will try to discuss the implications that the increase in agricultural production and therefore in water consumption had on water resources, especially on the need to construct infrastructure to store and distribute water for irrigation.

Our findings point at a gradual increase in the consumption of blue and green water to produce agricultural and food goods until 1962, with a smooth deceleration from 1930 to 1962, period that comprises the Spanish Civil War and the first twenty years of Franco's Dictatorship. This growing trend became notably marked during the period 1962-2008, when a strong growth in agri-food production and exports that significantly increased demand for water, took place. Although production patterns changed and crop and livestock yields notably improved, their effect was not enough to make up for the great increase in production happened during these years.

In the following section we review the methodology and explain the data used. Then in section 3 the main results are explained. Section 4 discusseson the findings. Finally, section 5 ends the paper with the main conclusions.

2. Methodology and data

2.1. Methodology

As a first step, we estimate the volume of water necessary for the production of Spanish agricultural and food goods, that is, embodied water in production. Thus, following the methodology proposed by Hoekstra and Hung (2005) for virtual water trade, we obtain the volume of water embodied in Spanish agri-food production. For a country c (Spain in our case), in year t, embodied water in production (m^3/year) can be obtained as the sum of embodied water in production in each of its p products, what yields:

$$EWP(c,t) = \sum_p d_p^c(c,p,t) * P_p^c(c,p,t) \qquad (1)$$

Where $EWP(c,t)$ represents the volume of water necessary for the production of agricultural and food products in c during year t (m^3).$d_p^c(c,p,t)$ represents the water content per unit of good p in the producer country c (m^3/Ton) and

$P_p^c(c,p,t)$is the volume of production of each product p in country c and year t (Ton). Equation1 is calculated for blue and green water.

Once estimated the volume of water embodied in production, we address the factors underlying the changes in water consumed for production. Firstly we get an identity in which embodied water in production equals the drivers responsible for its trajectory. After that, in order to analytically analyse trends in embodied water in production and get the forces contributing to this trend, a Decomposition Analysis (DA) is applied.

That way, departing from equation 1, embodied water in production can be expressed, in general terms, as dependent on three types of factors: water intensities, composition and scale of production:

$$EWP(c,t) = \sum_{p} w_{cpt} \cdot \left(\frac{P_{cpt}}{p_{ct}}\right) p_{ct} \qquad (2)$$

This can be expressed in matrix form as:

$$EWP(c,t) = \mathbf{w}'_{\mathbf{ct}}\mathbf{v}_{\mathbf{ct}}p_{ct} \qquad (3)$$

Where $\mathbf{w}'_{\mathbf{ct}}$ is a row vector including the virtual water content of each product c per ton produced in Spain during year t (measured in m^3/peseta), i.e., the water intensity.$\mathbf{v}_{\mathbf{ct}}$ $\widehat{E_i[p,t]}$ is a vector of the share of each product c in total Spanish production in period t and $p_{ct}$is a scalar that informs about the total value of Spanish production in year t (in constant pesetas of 1959).

Departing from equation 3, a DA is applied. This technique breaks down a time trend of an aggregated variable into a group of driving forces that can act as accelerators or retardants (Dietzenbacher and Los, 1998;Lenzen et al., 2001). In practice, there are different ways of solving this expression by way of exact decompositions. However, as Dietzenbacher and Los(1998) show, the simple average of the two polar decompositions can be considered as a good approximation of the average of the $n!$ exact decomposition forms.In our case, as decomposition is based on three factors we can obtain the 3! exact decompositions. Nonetheless, following Dietzenbacher and Los (1998) we obtain the simple average of the two polar decompositions.

Therefore, the two polar decompositionsof (3) can be written as:

$$\Delta EWP(c) = \Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct-1}}p_{ct-1} + \mathbf{w}_{\mathbf{ct}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct-1} + \mathbf{w}_{\mathbf{ct}}'\mathbf{v}_{\mathbf{ct}}\Delta p_c$$
$$= \Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct}}p_{ct} + \mathbf{w}_{\mathbf{ct-1}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct} + \mathbf{w}_{\mathbf{ct-1}}'\mathbf{v}_{\mathbf{ct-1}}\Delta p_c \qquad (4)$$

Taking the average of the terms in (4):

$$\Delta EWP(c) = \frac{\Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct-1}}p_{ct-1} + \Delta\mathbf{w}_{\mathbf{c}}'\mathbf{v}_{\mathbf{ct}}p_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{ct}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct-1} + \mathbf{w}_{\mathbf{ct-1}}'\Delta\mathbf{v}_{\mathbf{c}}p_{ct}}{2} + \frac{\mathbf{w}_{\mathbf{ct}}'\mathbf{v}_{\mathbf{ct}}\Delta p_c + \mathbf{w}_{\mathbf{ct-1}}'\mathbf{v}_{\mathbf{ct-1}}\Delta p_c}{2} =$$
$$\mathrm{IE}(\mathrm{c}) + \mathrm{CE}(\mathrm{c}) + \mathrm{SE}(\mathrm{c}) \qquad (5)$$

As a result, trends in embodied water in Spanish agricultural and food products can be explained on the basis of the intensity effect IE(c), which quantifies the contribution of variations in water intensities to changes in the volume of water embodied in production; composition effect CE(c),which explains changes in embodied water in production depending on changes in the share of products in trade andthe scale effect SE(c), which links changes in water embodied in production with changes in the volume of trade.

2.2. Data

Data for the volume of Spanish production in physical units (Tons) have been obtained from "Estadísticas Históricas de la Producción Agraria Española, 1859-1935" (GEHR, 1991)and "Anuario Estadístico de la Producción Agraria" (MAGRAMA, 1929-2010) for the period 1900-2009. When possible we get information for three years and take a simple average, trying to soften annual deviations. Despite most data were obtained from these sources, they do not contain information for 1860 and for some products in 1900. For that reason, we have added appendix 2 that describes the process of calculation for these data.

Regarding the quality of data used, we consider that they are reliable from 1929, i.e., from the moment in which the Ministry of Agriculture began publishing annual data for all crops and livestock products (GEHR, 1991). Data are also reliable for 1900, although some estimates were necessary. Appendix 2 explains how the data of the different agricultural productions for 1900 were obtained. Thus, the results from 1900 to 2010 offer a high degree of confidence and accuracy. Given the total lack of data for different agricultural products for 1860, we have estimated these data as explained in appendix 2. On the whole, these results for 1860 seem to be a reasonable estimation but it is not possible to reach definitive conclusions from them.

It is important to note that for live animals and crops to feed livestock (fodder cereals, fodder and other animal feed as oil seed cakes)[1]we have only considered the volume of water embodied in exports. That is, trying to avoid double counting we do not take into account the fodders and animals used to produce meat and dairy products, as they are already included on the water intensities of animals and derived products. Furthermore, as this paper focuses on the water embodied in the Spanish agricultural sector, we have subtracted the volume of water resources embodied in imported fodders utilized to feed livestock.

An accurate application of the DA requires data for the volume of production in constant monetary units. Therefore, production data have been expressed in constant 1959 pesetas. We have information for the production of 89 agricultural and food commodities in Spain (except for Canary Islands).

Water specific demand coefficients of crops and animal products have been taken from Mekonnen and Hoekstra (2011, 2012) respectively.Following Hoekstra et al. (2009) crop and livestock water requirements express the volume of water necessary (green or blue) per ton of product and are obtained as the ratio between evapotranspiration (ET) and yields (Y). As crop and climatic conditions in Spain seem to be stationary on time, it seems feasible to keep evapotranspiration constant (see appendix 1 for an examination of uncertainties). However, technological advances and seeds improvements happened from 1860 have caused important yield improvements. Thus, in line with Dalin et al. (2012) and Konar et al. (2013), water intensities have been modified as a function of Spanish yields series as follows:

[1] In the case of Maize, we consider hybrid maize as animal feed from 1960.

$$w_{cpt} = w_{cp} \frac{Y_{cp}}{Y_{cpt}} \qquad (6)$$

With w'_{ct} being the variable water coefficient for each product in the period of analysis, or *t=1860...2010*. w_{cp} w'_{c} is the crop or livestock water intensity given by Mekonnen and Hoekstra (2011, 2012). Y_{cp} Y_{c} represents the average yield of the reference period (1996-2005) considered by the above authors. Yield data have been taken from FAO (FAOSTAT, 2013). Y_{cpt} Y_{ct} gives information on annual product yields from 1860 to 2010. Spanish yields for the period 1900-1930 come from "Estadísticas Históricas de la Producción Agraria Española, 1859-1935" (GEHR, 1991), whereas from 1960 to 2010 they have been taken from FAOSTAT (2013).

Thus, the hypothesis that lies behind this approach is that changes in historical crop and livestock yields have notably affected water consumption per ton in the long term.

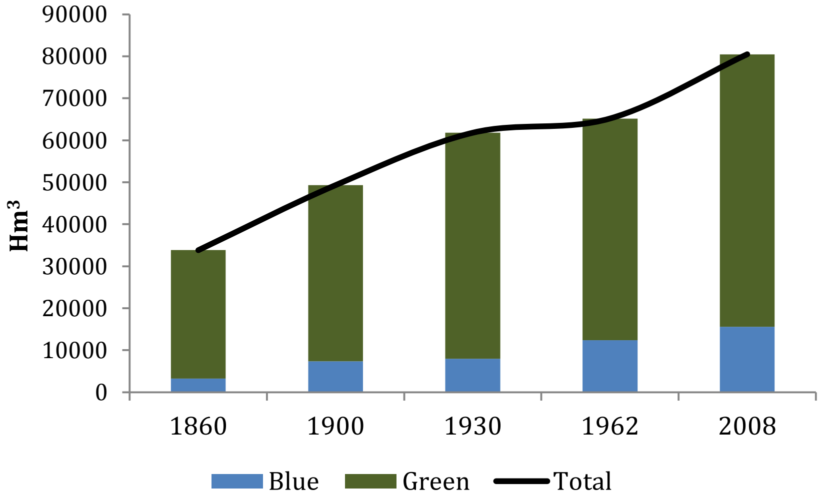
3. Results

3.1. Trends and patterns of embodied water in production

Water embodied in Spanish agricultural production tended to increase from 33,824 hm^3 in 1860 to 80,486 hm^3 in 2008, showing an average annual growth of 0.6% (Figure 1).

The volume of water consumed to produce agricultural and food products gradually grew until 1930, (average annual growth rates of 0.8% for green water and 1.3% for blue water), which fits well with a smooth growth of agricultural production in the same period. This increase flattened during the period that comprises the Spanish Civil war and the first years of Franco's dictatorship. It also coincides with the problems suffered by the Spanish agriculture and economy during those years. The agricultural production levels prior to the Civil War of 1936-39 did not recover until the mid-fifties, as a consequence of the isolation of the Spanish economy and the difficulties to import basic inputs for a modernizing agriculture such as fertilizers or machinery.

Figure 1: Water embodied in Spanish production (1860-2008)



Source: own elaboration from data on Mekonnen and Hoekstra (2011, 2012), GEHR (1991) and MAGRAMA (1929-2010)

From 1930 to 1962 the rise of embodied water in Spanish production decelerated. Whereas blue water consumption increased at 1.4% yearly, green water declined at an annual average rate of -0.06%. On the one hand, the growth of blue water embodied in production was mainly due to the increase in the production of cotton, a blue water intensive crop that was almost new and experienced an intense development with a high tariff protection. Other products as milk or sugar beet also increased its production considerably. On the other hand, the production of meat, a product with high green water content per ton produced, sank. From 1962 onwards, the volume of water for production soared from 65,186 hm^3 to 80,486 hm^3, growing at approximately 0.5% every year. During these years an abrupt growth of agricultural production happened, chiefly because of the great introduction of new technologies. Furthermore, changes in the composition of agricultural production, mainly owing to the development of the intensive stockbreeding industry, have enabled a new specialization that was not previously feasible given the scarcity of quality natural pastures.

Green water was the most important component of embodied water in production, representing about 85% on average of total water. Nevertheless, blue water consumption accounted for a growing share on time and grew at a faster pace (1.1%) than green water (0.5%) during the whole period.

Table 1: Composition of embodied water in production and average annual growth rates

Sitc rev.1 product classif.	1860	1900	1930	1962	2008	*1860-1900*	*1900-1930*	*1930-1962*	*1962-2008*	*1860-2008*
	Green water composition (%)					*Green water growth rates (%)*				
01 Meat and preparations	25.6	20.2	21.9	9.8	32.7	0.2	1.1	-2.5	3.1	0.7
02 Dairy products and eggs	6.7	7.6	14	32.2	16.5	1.1	2.9	2.6	-1	1.1
04 Cereals	44.3	37.9	32.2	24.6	13.1	0.4	0.3	-0.9	-1	-0.3
05 Fruit and vegetables	8.5	12.9	14.8	14.8	15.7	1.9	1.3	-0.1	0.5	0.9
06 Sugar	0	0.2	0.1	0.9	0.3	n.a.	-1.9	7.8	-2	n.a.
07 Spices	0	0	0	0	0	2.9	1.6	-3.1	-13.1	-3.9
11 Beverages	11.3	17.7	12	12.3	6.1	1.9	-0.5	0.0	-1.1	0.1
1210 Tobacco, unmanuf.	0	0	0	0.1	0	0	0.9	5.3	-1.2	0.9
22 Oil seeds, nuts and kernels	0.1	0.1	0	0.2	0.5	0.8	-6.1	12.2	2	2.1
26 Textile fibres	0.5	0.1	0.1	1	0.4	-3.3	0.7	7.6	-1.2	0.4
42 Fixed vegetable oils and fats	3	3.3	4.9	4.1	14.7	1	2.2	-0.6	3.3	1.6
Total	100	100	100	100	100	0.8	0.8	-0.1	0.4	0.5
	Blue water composition (%)					*Blue water growth rates (%)*				
01 Meat and preparations	6.7	4.3	4.2	4.2	18.2	0.2	1.1	1.5	3.7	1.8
02 Dairy products and eggs	8.7	8.3	13.6	18.9	10.2	1.1	2.9	2.5	-0.9	1.2
04 Cereals	20.2	15.4	14.6	8.3	8.4	0.6	1.1	-0.3	0.5	0.5
05 Fruit and vegetables	26.3	29.9	34.6	26.8	30.0	1.6	1.7	0.7	0.7	1.2
06 Sugar	0.0	2.0	0.8	5.2	1.6	n.a.	-1.9	7.8	-2.0	n.a.
07 Spices	0.1	0.1	0.1	0.0	0.0	2.9	1.6	-3.1	-13.1	-3.9
11 Beverages	19.4	25.1	15.0	9.4	4.5	1.9	-0.5	0.0	-1.1	0.1
1210 Tobacco, unmanuf.	0.0	0.0	0.0	0.1	0.0	0.0	0.9	5.3	-1.2	0.9
22 Oil seeds, nuts and kernels	0.4	0.3	0.0	1.0	2.2	0.8	-6.1	13.3	2.1	2.3
26 Textile fibres	2.4	0.4	1.7	21.9	10.0	-3.2	6.3	9.9	-1.2	2.0
42 Fixed vegetable oils and fats	15.8	14.2	15.4	4.2	14.7	1.0	1.5	-2.5	3.3	1.0
Total	100.0	100.0	100.0	100.0	100.0	1.3	1.3	1.5	0.5	1.1

Source: own elaboration from data on Mekonnen and Hoekstra (2011, 2012), GEHR (1991) and MAGRAMA (1929-2010)

Table 1 displays the composition of production in terms of the volume of water consumed as well as the average annual growth rates for each group of products. If we look first at the volume of green water necessary to meet production demands, it is observed that cereals were the most important group for all the periods, accounting for 30% of total green water on average. Nevertheless, they were gradually reducing their shares until 2008. Cereals were the main source of calories, at least until Spain reached a high level of per capita income. From that moment onwards, its diet converged towards the most developed countries, with an important weight of calories of animal origin. Wheat was the main cereal consuming green water. Meat had also a significant impact on embodied green water in production. As we previously said, it dropped in 1962 but the trend reversed by 2008, when it represented 32.7% of total green water. This fact can be explained by the great increase happened from 1962 to 2008, when meat grew at 3.2% every year.

The group formed by fruits and vegetables was also noteworthy, with increasing shares and significant positive growth rates. Nuts and citrus fruits stand out in this group. Dairy products (milk) depict a notable growth of share from 1900 until 1962. In 2008 it represented 16.5% of total green water consumption. The expansion of dairy products in Spain, very late compared to other countries, explains this trend (Hernández-Adell, 2012; Collantes, 2014). Vegetable oils, with olive oil as the main good, represented about 4% until 1962. From that moment on, this group was 15% of total green water embodied in agricultural production mostly provoked by the increase in olive oil production. Eventually beverages, with wine as the most significant item, depict percentages around 12% that decreased by 2008. The importance of wine production throughout the period analysed explains its significant share. This was particularly intense from the end of the XIX century when the export boom to France reached its maximum value and the weight of wine production on agricultural production also peaked (Fernández and Pinilla, 2014).

As for blue water, the picture was somehow different. Fruits and vegetables were the most representative being responsible for about 30% of blue water requirements and kept quite stable until the end of the XX century. Again nuts and citrus fruits were the most representative crops. The volume of blue water needed by this group grew at an annual rate of 1.2%. The importance of fruits and vegetables as consumers of blue water has been largely influenced by the strong growth of its production, mostly destined for foreign markets. From the mid-XIX century fruit and vegetable exports grew strongly, but especially since the late XIX century (Pinilla and Ayuda, 2009). Its importance was rising, accounting for approximately 40% of blue virtual water exports in 1930 (Duarte et al., 2014b). In the years after the Civil War, there was a noticeable decline in the exports of Spanish fruits, however they recovered from the early seventies and then grew at a fast pace, particularly after the Spanish accession in the European Union in 1986 (Clar et al., 2014). Cereals were also important consumers of blue water. Although this group displays positive growth rates, they increased below average, what caused a gradual loss of share from 20% in 1860 to 8.4% in 2008. In this case, rice entailed over 60% of the volume of blue water consumed by cereals. Dairy products and meat exerted a notable contribution to the blue water footprint of agriculture; although to a less extent than green water. Besides, olive oil and wine also consumed important volumes of blue water. Olive oil remained quite stable during the period considered, but fell in 1962. Wine decreased its share going from 25% in 1900 to 4.5% in 2008. Finally it is important to highlight the high share of textile fibres in 1962, explained by the great rise of cotton production, a high blue water intensive crop that showed intense growth rates from 1900 to 1962.

3.2. Factors explaining changes in embodied water in production

As we have seen, the volume of water necessary to produce agricultural and food goods notably increased from 1860 to 2008. It was mainly triggered by an intense increase in production that looked for meeting the growing demands of a developing society and international markets. Table 2 displays the contribution of these factors to changes in embodied water. On the whole, scale effect had a direct effect on green and blue water consumption from 1860 to 2010. Compositional changes with decreasing shares of green water embodied in wheat, rye and ovine meat and blue water embodied in wheat, flax and grapes boosted water consumption deceleration. Moreover, the growth of crop and livestock yields that resulted in decreasing water intensities, made water consumption upward trend to slow down. Whereas composition effect was more important for green water, intensity effect had a largest effect on blue water.

It is possible to find some differences depending on the sub-period chosen. During the first stage (1860-1900) only the growing agricultural production made green water consumption to rise[2]. However, composition (27%) and scale (73%) triggered the increase in blue water. Thus, both scale effect and productive changes towards fruits, vegetables and wine made blue water to increase. From 1900 to 1930 the embodied water increased by 14 km^3. The growing production of agricultural and food products encouraged the whole increase in green and blue

[2] As there are no data on crop productivity for 1860, we have assumed that it was the same as in 1900. That's why between 1860 and 1900 the contribution of the intensity effect is 0.

water. However, the introduction of new technical inputs, like fertilizers entailed important yield improvements, which partially made up for the rise of embodied water in production. Without the former effect, total water consumption would have been 4.3 km^3 higher. The period 1930-1962 is quite peculiar. If green water decreased by 1.8 km^3, blue virtual water kept on growing. The former declined as a result of the contraction on agricultural production taken place during the Spanish Civil War and Franco's Dictatorship. On the contrary, the latter increased over 3 km^3 mainly due to changes in production patterns. As we previously commented, from 1930 to 1962 the production of blue water intensive products such as cotton, sugar beet or milk was promoted entailing the increase in blue water consumption.

Table 2: Decomposition analysis of embodied water

	Effects	1860-1900	1900-1930	1930-1962	1962-2008	1860-2008
Green virtual water	**Scale (%)**	102	153	-758	485	366
	Composition (%)	-2	-23	185	-163	-137
	Water intensity (%)	0	-30	673	-222	-129
	Δ virtual water in production (km3)	11.8	11.7	-1.8	16.4	38.1
Blue virtual water	**Scale (%)**	73	135	80	609	201
	Composition (%)	28	-1	126	-318	-31
	Water intensity (%)	0	-34	-106	-191	-70
	Δ virtual water in production (km3)	2.6	2.2	3.4	3.1	11.3

Source: own elaboration from data on Mekonnen and Hoekstra (2011, 2012), GEHR (1991) and MAGRAMA (1929-2010)

Finally during the last period (1962-2008), green and blue virtual water increased 38 km^3 and 11 km^3 respectively, as a result of the great increase in production. As it is observed in Table 2, composition and intensity effects display negative sign indicating that, without their negative contribution, the increase in the volume of water consumed for production would have been even greater (100 km^3 and 11 km^3 for green and blue water respectively). The notable contribution of the intensity effect to water consumption leveling off can be explained by the strong rise in yields in this period. It occurred as a result of the massive use of fertilizers, pesticides, hybrid seeds and modern inputs that significantly increased the productivity of land in agriculture in developed countries.

4. Discussion

On the one hand, the increase in the volume of water consumed by agricultural production was 74% due to green water on average. Although green water cannot be regulated and stored, it is essential for crop and livestock production. The existing data indicate that harvested land gradually expanded throughout the period considered, from 16,012,000 Ha in 1860 (Jimenez Blanco, 1986) to approximately 21,110,000 Ha in 1972 decreasing to 17,793,000 in 2005 (Martín-Retortillo and Pinilla, 2013). This growth was sometimes biased towards rainfed crops like wheat, vines or olive trees given climatic and land conditions. This expansion involved important environmental impacts. Firstly, as Bielsa et al. (2011) show, during the second half of the XXcentury, depopulation in the Ebro basin lead the growth of natural vegetation increasing the consumption of green water and reducing the endowment of blue water. Besides, Fader et al. (2011) point at the impact of the rise in harvested land in terms of land use.

On the other hand, the expansion of production and the substitution of certain crops also entailed growing requirements of blue water. Obtaining water for irrigation had important economic effects, given the necessary heavy capital investments and the uncertainty of their results.Moreover, irrigation infrastructure entailed environmental impacts.

Looking at Figure 1 and Table 2, we observe that the evolution of Spanish production of agricultural products involved an increasing pressure on the needs of water for irrigation. Between 1860 and 2008 it was necessary to confront an absolute increase, of some 11 km^3 of blue water. The demand for water for irrigation was linked to the needs of a developing foreign sector, but also to the self-same increase in agricultural production, destined largely to the domestic market, playing an essential role.

Attempting to increase irrigation had been a traditional way for farmers to try to improve their production. The climatic conditions of a large part of Spain, namely scarce and irregular rainfall with seasonal drought, had resulted in a very long tradition of harnessing the river systems to irrigate arid land. Numerous small-scale hydraulic infrastructures had been built. The main aim of these efforts to expand the irrigated area was to ensure harvests rather than to raise productivity or change the use of the land. In the XIX century, the increase in domestic demand, due principally to population increase, in a relatively protectionist context, offered attractive possibilities to increase agricultural production. Furthermore, the integration of the Spanish economy in the first globalisation meant that foreign demand for agricultural products was one of the driving forces behind the development of agricultural production (Garrabou and Sanz, 1985; Clar and Pinilla, 2009). Accordingly, many initiatives arose to attempt to achieve more water and thereby increase the crops benefiting from it. Very scant progress was made with irrigation throughout most of the XIX century.

With the data available it is impossible to quantify by how much the irrigated area increased in the XIX century. The scarce quantitative data and some qualitative figures permit two conclusions to be reached. Firstly, the increase in the capacity to store water and in this way ensure and increase the irrigated surface area was very small. As a result, faced with the difficulties in achieving in this way a substantial increase in the supply of water, in those places with stronger expectations of developing export-orientated crops, which required not only irrigation water but also regularity in its supply, a private effort to extract water from the subsoil in previously dry land was combined with a change in the uses of soil, dedicating land previously used for wheat or other crops to the promising export crops.

The evidence which supports the scarce increase in the capacity for water storage is the fact that in the second half of the XIX century the reservoirs constructed which had as sole or shared objective the supply of water for irrigation, only increased it by less than 50 hm^3. Although it is true that it doubled theexisting capacity in Spain as a whole, it continued to offer extremely limited possibilities for storing water for irrigation. The scanty increase in storage capacity was not due to the shortage of business initiatives for the implementation of irrigation works. On the contrary, in the second half of the XIX century there was unleashed a fever for the constitution of companies to perform such waterworks. In some areas of Spain, especially in the Ebro valley, their results were notable (Pinilla, 2008; Ramón, 2013). However, the problems with this type of canal is that as they did not have head dams to ensure the supply of water during the periods of greatest water stress they did not permit a change in the uses of land, but instead greater and more regular production of traditional crops. The obstacle for the construction of the necessary dams was dual: technical and economic. The technical obstacle was the backwardness of the technologies capable of constructing dams which resisted the pressure of water. The economic handicap was related to the heavy investment necessary and its long amortization period for private investors.

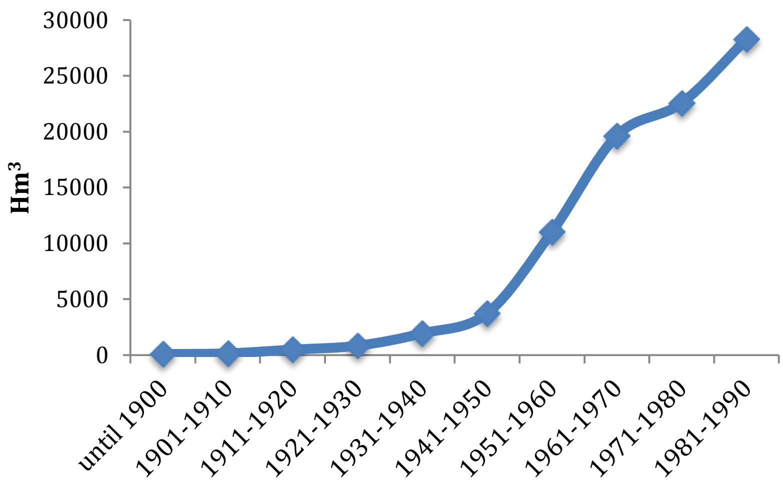
These problems encouraged farmers, interested in obtaining sufficient water for the expansion of crops, to look for alternatives, namely changes in the uses of land in traditional irrigated land or the drilling of wells to extract water in dry farming areas. Such types of initiatives were most highly developed in the region of Valencia.

In the first third of the XX century, the most specialised regions in Mediterranean horticultural production went through an intensification in the substitution of irrigated traditional crops by fruit and a substantial increase in the extraction of water from the subsoil, making massive use of new technical resources such as electricity or petrol engines, which tended to replace the traditional systems of treadmills and manual pumps which had a limited capacity for elevating water. Yet even the traditional treadmills were improved by the use of iron in many of their essential parts. These new technologies were also applied to pump surface water.

With regard to the use of new technologies, these had begun to spread with the use of steam for pumping water from wells since the middle of the XIX century, especially for the irrigation of oranges in Valencia. Their high cost considerably limited their diffusion (Garrabou and Sanz, 1985). Together with the traditional lifting pumps, from the beginning of the XX century there began to be employed others driven by petrol, lean gas or electricity. In 1916 these still accounted for a small percentage of the land area irrigated with underground water (approximately 10%, while treadmills constituted over 50%), but in the lifting of surface water it already represented over 50% of the surface irrigated using this system, with a clear predominance of electric pumps. The expansion of such technologies in the following years was very rapid. The 6,000 pumps powered by fossil fuels which existed in 1916 rose to 24,000 in 1932. Almost half were electric motors and 60% were located in the Mediterranean region, the most highly specialised in horticultural export products (Calatayud and Martínez Carrión, 1998 and 2005).

However, in the first third of the XX century not only private enterprise played a key role through the drilling of wells and the use of modern machinery to lift water. Of substantial importance was the assumption by the state of the principal responsibility for the construction of large waterworks. This new policy implied that the state would assume responsibility for a significant part of the financing of the large-scale hydrological works (dams and main and secondary canals), while farmers would bear the cost of levelling the agricultural plots, channelling the water within them and establishing the connections between the irrigation ditches and their plots (Pinilla, 2006). This active role of the state in the development of large-scale water works was clearly influenced by the effects of the depression suffered by European agriculture at the end of the XIX century, Furthermore, the possible multiple use of dams, to produce hydroelectricity and at the same time to provide water for agriculture, facilitated the development of waterworks (Pinilla, 2008).

Figure 2: Accumulated reservoir capacity in Spain, 1900-1990 (dams for irrigation)

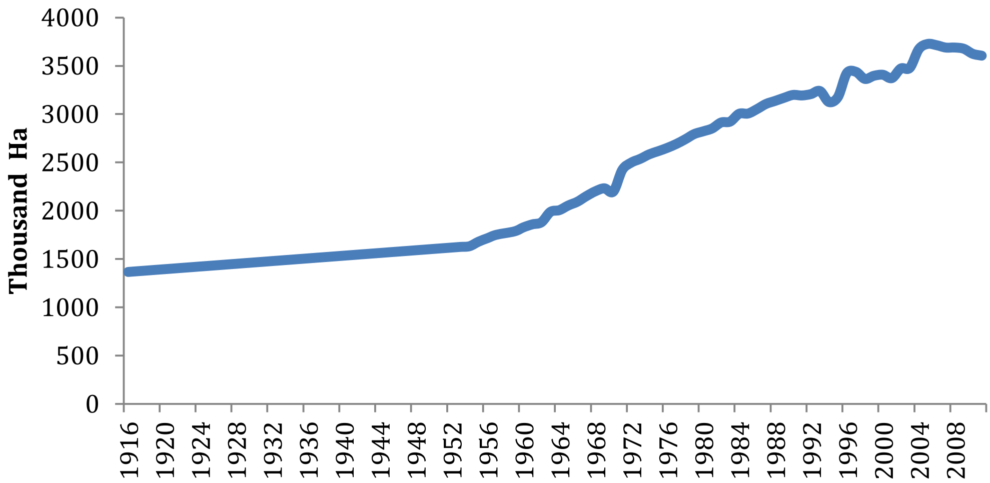


Source: Own calculations from data presented in Dirección General de Obras Hidráulicas(1992)

Spain experienced, in the first third of the XX century, a rapid increase in the construction of dams (Figure 2). While in 1900 their capacity for water storage for irrigation was 82.2 hm^3, between that date and 1930 this increased by 744 hm^3, that is to say, an increase of 905%. Between 1930 and 1940 this increased by a further 1,105 hm^3, thereby more than doubling in only 10 years the existing dam capacity (Pinilla, 2006).

In summary, whether through the drilling of wells and the use of modern machinery for the lifting of water or through an intensive programme of large waterworks, the capacity to supply water for irrigation increased at an unprecedented rhythm and quantity during the first third of the XX century.

Figure 3: Irrigated area, 1916-2011



Source: Data from 1917 to 1953 were not available. We linearly interpolated information between 1916 and 1954. Source: Own calculation from data in Junta Consultiva Agronómica (1918) and MAGRAMA (1929-2011)

But the boost to the completion of waterworks was spectacular during the Franco's dictatorship. The construction of reservoirs and channels thus became one of the central pillars of Franco's agricultural policy. The result was a dramatic increase in reservoirs capacity, which dwarfs previous achievements. As Figure 2 depicts, between 1950 and 1970 dams had a control capacity of nearly 16,000 hm3, representing about half of the current capacity and more than five times the pre-1950. The large irrigation schemes developed lead to a very strong increase in agricultural irrigated area (see Figure 3). The new regulation capacity of dams that ensured a regular supply of water resulted in important land use changes. Thus, crops that in Spain could only grow under irrigation conditions were gradually replacing traditional crops.

In the democratic period that started in 1977, water, water policy and the extension of irrigation were still important topics in the Spanish economy and in the social and political debate. Dam construction went on until the late XX century.

It allowed carrying on with the expansion of the irrigated area at a slower pace than in the previous two decades, but still high. The result has been a clear trend towards the concentration of production in the irrigated area, which despite being smaller than rainfed land, represents more than half of agricultural production nowadays. Irrigation has become essential for the Spanish agricultural production. In a context of high agri-food trade opening, a great part of the expansion of irrigation has been allocated towards export products (Clar et al., 2014).

However, the new democratic framework allowed an intense debate on water policy, which hadbecome one of the important issues in the Spanish political debate. The construction of costly infrastructure to transfer water from the Ebro River, Spain's largest river system, to the Mediterranean coast has been the most hotly debated issue, strongly influenced by clashes between the territorial interests of the Autonomous Communities (political regions) that opposed the Ebro transfer (Aragon and Catalonia) and those that were in favor (Valencia, Murcia and Andalusia).

From a social point of view, it is also important to acknowledge the popular opposition which has emerged since the beginning of the 1990s to the execution of further large-scale water regulation projects in the mountain areas. This has taken the form of a new unwillingness of people living in the affected areas to having their land or houses expropriated. As a result, there has been a clash between their interests and those of the farmers, who have anticipated that such regulatory works would result in a further expansion of the irrigated area or in an improvement in the supply to those already in existence. It is the view of those who oppose these large-scale projects that the mountain areas paid a very high price throughout the XX century in terms of the flooding of population centers and cultivated lands, and the enforced movement of whole populations as a consequence of reservoir construction

From an academic point of view, the most interesting aspect is the growing questioning of the 'classical' policies aimed at increasing the supply of cheap water, and the emergence of a 'new water culture', which places stress on demand management, water saving measures, and higher prices to act as an incentive for efficiency. When viewed from this perspective, it is assumed that policies aimed at increasing supply made sense throughout the majority of the XX century, to the extent that they solved either simultaneously or in parallel three key problems faced by underdeveloped, predominantly agricultural, countries, with un-regulated rivers and limited deposits of fossil fuel, namely the provision of drinking water, the development of irrigation and the expansion of hydro-electric production. The change in the socio-economic context and the significant increase in the supply of water that had been made possible by the very high levels of hydrological regulation have resulted in a new paradigm being proposed, whose key elements are concern for sustainable development, the integrated management of water and territory and the management of water demand.

5. Conclusions

The strong expansion of agricultural production taken place in Spain between 1860 and 2010 lead to growing needs of water resources. Actually, water consumption more than doubled during these years. Although the sub-periods chosen differ depending on economic, social or institutional circumstances, on the whole, it was the scale of production the main factor driving water consumption. Products substitution as well as crop and livestock yield increases prevented a higher growth of embodied water in production. On the one hand, green water was essential for the development of the agricultural sector and its consumption rose associated with the upward trend followed by harvested land. On the other hand, crops substitution would have not been possible without the key role of irrigation. Irrigated area gradually increased during these years, and with it, the consumption of blue water.

Accordingly, the development of the Spanish agricultural sector was closely linked with technological developments that allowed obtaining and storing water in an easier and cheaper way. However, it was essential to overcome important economic obstacles to build water infrastructure. In this respect, the role of the government as the main funder of large waterworks was determinant.

Nevertheless, it seems quite clear that the Spanish agricultural expansion was carried out neglecting its environmental impacts, considering water resources only as a productive input. In addition, the fact that most water infrastructure was funded mainly by the government for a long time, even using hydraulic policy as a political instrument, could have separated the Spanish society from the actual cost of water as well as from the impact of economic growth on the environment. The excessive water consumption together with an unequal and unbalanced agricultural policy has resulted in an alarming water scarcity in many Spanish regions today. Therefore, the Spanish case in which a long term agricultural transition happened neglecting its environmental consequences should be taken as an illustration of the way that long term development processes affect water resources. In this context, it seems essential that economic development and environmental protection go together to avoid unintended effects in the near future.

6. References

Allan, J.A., 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In: ODA, Priorities for water resources allocation and management. ODA, London, pp 13-26

Allen, R.C., 2009. The British Industrial Revolution in Global Perspective (New Approaches to Economic and Social History).Cambridge University Press, New York.

Barciela, C., García, A., 1986. Un análisis crítico de las series estadísticas de los precios del trigo entre 1937 y 1980, in: Garrabou, R., Barciela, C., Jiménez Blanco, J.I. (Eds.), Historia agraria de la España contemporánea, vol. 3: el fin de la agricultura tradicional (1900-1960). Crítica, Barcelona, pp. 499-533.

Barciela, C., López, I., 2000. El agua en la historia de España Prensas de la Universidad de Alicante, Alicante.

Bielsa, J., Cazcarro, I., Sancho Y., 2011. Integration of hydrological and economic approaches to water and land management in Mediterranean climates: an initial case study in agriculture. Spanish Journal of Agricultural Research 9, 1076-1088.

Calatayud, S., MartínezCarrión, J.M., 1998.El cambio técnico en los sistemas de captación e impulsión de aguas subterráneas para riego en la España mediterránea, in: Garrabou, R., Naredo, J.M. (Eds.), El Agua en los Sistemas Agrarios. Una Perspectiva Histórica. Fundación Argentaria, Madrid, pp. 15-40.

Calatayud, S., Martínez Carrión, J.M., 2005. El cambio tecnológico en el uso de las aguas subterráneas en la España del Siglo XX: un enfoque regional. Revista de historia industrial 25, 51-116.

Carpintero, Ó., Naredo, J.M., 2006. Sobre la evolución de los balances energéticos de la agricultura española, 1950-2000. HistoriaAgraria, pp. 531-556.

Chapagain, A.K., Hoekstra, A.Y., 2011. The blue, green and grey water footprint of rice from production and consumption perspectives. Ecological Economics 70, 749-758.

Clar, E., 2008. Más allá de 1936: la crisis de la agricultura tradicional española en perspectiva, 1900-1975. AGER. Revista de Estudios sobre Despoblación y Desarrollo Rural 7, 109-147.

Clar, E., Pinilla, V., 2009. The contribution of agriculture to Spanish economic development, in: Lains, P., Pinilla, V. (Eds.), Agriculture and Economic Development in Europe since 1870. Routledge, London, pp. 311-332.

Clar, E., Pinilla, V., Serrano, R., 2014. El comercio agroalimentario español en la segunda globalización,1951-2011. Working Paper Asociación Española de Historia Económica.

Collantes, F., 2014. La evolución del consumo de productos lácteos en España, 1952-2007. Revista de Historia Industrial.

Cussó, X., Garrabou, R., Olarieta, J.R., Tello, E., 2006b. Balances energéticos y usos del suelo en la agricultura catalana. Una Comparación Entre Mediados del Siglo XIX y Finales del Siglo XX Historia Agraria 40, 471–500.

Cussó, X., Garrabou, R., Tello, E., 2006a. Social metabolism in an agrarian region of Catalonia (Spain) in 1860–1870: Flows, energy balance and land use. Ecological Economics 58, 49-65.

Dalin, C., Konar, M., Hanasaki, N., Rinaldo, A., Rodriguez-Iturbe, I., 2012. Evolution of the global virtual water trade network. Proceedings of the National Academy of Sciences of the United States of America 109, 8353.

Dietzenbacher, E., Los, B., 1998. Structural Decomposition Techniques: Sense and Sensitivity. Economic Systems Research 10, 307-324.

Dirección General de Obras Hidráulicas, 1992. Inventario de presas españolas. Ministerio de Obras Públicas y Transportes, Madrid.

Duarte, R., Pinilla, V., Serrano, A., 2013. Is there an environmental Kuznets curve for water use? A panel smooth transition regression approach. Economic Modelling 31, 518-527.

Duarte, R., Pinilla, V., Serrano, A., 2014a. Looking backward to look forward: water use and economic growth from a long-term perspective. Applied Economics 46, 212-224.

Duarte, R., Pinilla, V., Serrano, A., 2014b. The effect of globalisation on water consumption: a case study of the Spanish virtual water trade, 1849-1935. Ecological Economics 100, 96-105.

Fader, M., Gerten, D., Thammer, M., Heinke, J., Lotze-Campen, H., Lucht, W., and Cramer, W., 2011.Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade.Hydrol. Earth Syst. Sci. Discuss., 8, 483-527.

FAO, 2013. FAOSTAT Database on Agriculture, http://faostat.fao.org/ [Last accessed: December 2013].

Federico, G., 2005. Feeding the World: An Economic History of World Agriculture, 1800-2000 Princeton University Press, Princeton.

Fernández, E., Pinilla, V., 2014. Historia Economica del Vino en España, 1850-2000. Mediterráneo Económico 25, 41-62.

Fernández-Clemente, E., 2000. Un siglo de obrashidráulicas en España. De la utopía de Joaquín Costa a la intervención del Estado Faculta de Ciencias Económicas y Empresariales de la Universidad de Zaragoza, Zaragoza.

Fischer-Kowalski, M., Haberl, H., 1993.Metabolism and colonization.Modes of production and the physical exchange between societies and nature. Innovation: The European Journal of Social Science Research 6, 415-442.

Gales, B., Kander, A., Malanima, P., Rubio, M., 2007.North versus South: Energy transition and energy intensity in Europe over 200 years. EuropeanReview of EconomicHistory 11, 219-253.

Gallego, D., 2001. Historia de un desarrollo pausado: integración mercantil y transformaciones productivas de la agricultura española, in: Pujol, e.a. (Ed.), El Pozo de Todos los Males. Sobre el Atraso de la Agricultura Española Contemporánea. Crítica, Barcelona, pp. 147–214.

Garrabou, R., Sanz, J., 1985. La agricultura española durante el siglo XIX: ¿inmovilismo o cambio?», in: Garrabou, R., Sanz, J. (Eds.), Historia económica de la España contemporánea 2. Expansión y crisis (1850-1900). Crítica, Barcelona, pp. 7-191.

Garrabou, R., Naredo, J.M., 1999. El agua en los sistemas agrarios. Una perspectiva histórica (1999). Visor/Argentaria, Madrid.

GEHR, 1983. Notas sobre la producción agraria española, 1891-1931. Revista de Historia Económica I, 185-252.

GEHR, 1991. Estadísticas históricas de la producción agraria española, 1859-1935. Ministerio de Agricultura, Pesca y Alimentación, Madrid.

Gil-Olcina, A., Morales-Gil, A., 1992. Hitos históricos de los regadíos españoles Ministerio de Agricultura, Madrid.

González de Molina, M., 2002. Environmental constraints on agricultural growth in 19th century granada (Southern Spain). EcologicalEconomics 41, 257-270.

González de Molina, M., 2010. Crecimiento agrario y sostenibilidad de la agricultura española en los siglos XVIII y XIX, in: Robledo, R. (Ed.), Sombras del progreso. Las huellas de la historia agraria. Crítica, Barcelona, pp. 321-352.

Guzmán Casado, G., González de Molina, M., 2006. Tras los pasos de la insustentabilidad : agricultura y medio ambiente en perspectiva histórica (siglos XVIII-XX) Icaria, D.L., Barcelona

Hernández Adell, I., 2012. La difusión de un nuevo alimento: producción y consumo de leche en España, 1865-1936. Tesis de Doctorado, Facultad d'Economia i Empresa, Universitat Autónoma de Barcelona.

Herranz, A., 2004. La dotación de infraestructuras en España, 1844-1935. Banco de España, Madrid.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., 2011. Water footprint assessment manual: Setting the global standard, Earthscan, London, UK.

Hoekstra, A.Y., Hung, P.Q., 2005. Globalisation of water resources: International virtual water flows in relation to crop trade. Global Environmental Change 15, 45-56.

Hoekstra, A.Y., Mekonnen, M.M., 2012. The water footprint of humanity.Proceedings of the National Academy of Sciences 109, 3232–3237.

Infante-Amate, J., 2012a. The Ecology and History of the Mediterranean Olive Grove: The Spanish Great Expansion, 1750 - 2000. Rural History 23, 161-184.

Infante-Amate, J., 2012b. «Cuántos siglos de aceituna». El carácter de la expansión olivarera en el sur de España (1750-1900). Historia agraria: Revista de agricultura e historia rural.

Infante-Amate, J., González de Molina, M., Vanwalleghem, T., Soto Fernández, D., Gómez, J.A., 2013. Erosion in the Mediterranean: The Case of Olive Groves in the South of Spain (1752–2000). Environmental History 18, 360-382.

Infante-Amate, J., González de Molina, M., 2013.The Socio-Ecological Transition on a Crop Scale: The Case of Olive Orchards in Southern Spain (1750–2000). Hum Ecol 41, 961-969.

Iriarte-Goñi, I., Ayuda, M.-I., 2008.Wood and industrialization: Evidence and hypotheses from the case of Spain, 1860-1935. Ecological Economics 65, 177-186.

Iriarte-Goñi, I., Ayuda, M.-I., 2012.Not only subterranean forests: Wood consumption and economic development in Britain (1850–1938). EcologicalEconomics 77, 176-184.

Jiménez Blanco, J.I., 1986. Introduction, in: Garrabou, R., Barciela, C., Jiménez Blanco, J.I. (Eds.), Historia agraria de la España contemporánea. 3. El fin de la agricultura tradicional (1900-1960). Editorial Crítica, Barcelona.

Kander, A., Lindmark, M., 2004. Energy consumption, pollutant emissions and growth in the long run: Sweden through 200 years. European Review of Economic History 8, 297-335.

Kastner, T., 2009. Trajectories in human domination of ecosystems: Human appropriation of net primary production in the Philippines during the 20th century. Ecological Economics 69, 260-269.

Kohlheb, N., Krausmann, F., 2009. Land use change, biomass production and HANPP: The case of Hungary 1961–2005. Ecological Economics 69, 292-300.

Konar, M., Hussein, Z., Hanasaki, N., Mauzerall, D.L., Rodriguez-Iturbe, I., 2013. Virtual water trade flows and savings under climate change. Hydrology and Earth System Sciences 17, 3219-3234.

Krausmann, F., 2001. Land use and industrial modernization: an empirical analysis of human influence on the functioning of ecosystems in Austria 1830–1995. Land Use Policy 18, 17-26.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., Fischer-Kowalski, M., 2009.Growth in global materials use, GDP and population during the 20th century.Ecological Economics 68, 2696-2705.

Krausmann, F., Gingrich, S., Haberl, H., Erb, K.-H., Musel, A., Kastner, T., Kohlheb, N., Niedertscheider, M., Schwarzlmüller, E., 2012. Long-term trajectories of the human appropriation of net primary production: Lessons from six national case studies. Ecological Economics 77, 129-138.

Krausmann, F., Haberl, H., 2002. The process of industrialization from the perspective of energetic metabolism: Socioeconomic energy flows in Austria 1830–1995. Ecological Economics 41, 177-201.

Krausmann, F., Schandl, H., Schulz, N.B., 2003.Long-term industrial transformation. A comparative study on the development of social metabolism and land use in Austria and the United Kingdom 1830–2000. Social Ecology Working Paper 70.

Krausmann, F., Schandl, H., Sieferle, R.P., 2008. Socio-ecological regime transitions in Austria and the United Kingdom. Ecological Economics 65, 187-201.

L'Vovich, M.I., White, G.F., 1990. Use and transformations of terrestrial water systems, in: The earth as transformed by human action: Global and regional changes in the biosphere over the past 300 years. Cambridge University Press, Cambridge, UK.

Lenzen M, Wiedmann T, Barney F, Dey C, Widmer-Cooper A, Williams M, R, O., 2001. Forecasting the Ecological Footprint of Nations: a blueprint for a dynamic approach, ISA Research Paper 07/01.

MAGRAMA, 1929-2010. Anuario Estadístico de la Produccion Agraria http://www.magrama.gob.es/es/estadistica/temas/publicaciones/anuario-de-estadistica/default.aspx.

MAGRAMA, 2013. Gestión sostenible de regadíos, http://www.magrama.gob.es/es/agua/temas/gestion-sostenible-de-regadios/.

Martín-Retortillo, M., Pinilla, V., 2012. Why did agricultural labour productivity not converge in Europe from 1950 to 2005? European Historical Economics Society Working papers 0025.

Martín-Retortillo, M., Pinilla, V., 2013.Patterns and causes of growth of Europeanagriculturalproduction, 1950-2005 Documentos de Trabajo (DT-AEHE) 1302, Asociación Española de Historia Económica.

Marull, J., Pino, J., Tello, E., 2008. The loss of territorial efficiency: a landscape ecology analysis of the land-use changes in a West Mediterranean agriculture during the last 150 years (Vallès County, Catalonia, 1853-2004). Global Environment 2, 114–152.

McNeill, J.R., 2000. Something New Under the Sun: An Environmental History of the Twentieth-Century World. W. W. Norton & Company, New York.

Mekonnen, M., Hoekstra, A., 2012.A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems 15, 401-415.

Mekonnen, M.M., Hoekstra, A.Y., 2011. The green, blue and grey water footprint of crops and derived crop products.Hydrol. Earth Syst. Sci. 15, 1577-1600.

Musel, A., 2009. Human appropriation of net primary production in the United Kingdom, 1800–2000: Changes in society's impact on ecological energy flows during the agrarian–industrial transition. Ecological Economics 69, 270-281.

Pinilla, V., 2006. The development of irrigated agriculture in twentieth-century Spain: A case study of the Ebro basin. AgriculturalHistoryReview 54, 122-141.

Pinilla, V., 2008. Gestión y usos del agua en la cuenca del Ebro en el siglo XX. PrensasUniversitarias de Zaragoza, Zaragoza.

Pinilla, V., Ayuda, M.I., 2009 Foreign markets, globalisation and agricultural change in Spain, in: Pinilla, V. (Ed.), Markets and Agricultural Change in Europe from the 13th to the 20th century. BrepolsPublishersTurnhou, pp. 173-208.

Prados de la Escosura, L., 2003. El progreso económico de España (1850-2000). Fundación BBVA, Bilbao.

Ramón, R., 2004. L’agricultura de regadiu a la Catalunya contemporània: elscanalsd’Urgell, 1860-1960. UniversitatPompeuFabra, Barcelona.

Ramón, R., 2013. Cambio agrario, uso del suelo y regadío: el impacto del canal de Urgell, 1860-1935. Historia Agraria 59, 43-94.

Rubio, M.d.M., 2005. Energía, economía y CO2: España 1850-2000. Cuadernos Económicos de ICE 70, 51-71.

Schwarzlmüller, E., 2009. Human appropriation of aboveground net primary production in Spain, 1955–2003: An empirical analysis of the industrialization of land use. Ecological Economics 69, 282-291.

Simpson, J., 1995. Spanish agriculture: the long Siesta, 1765-1965. Cambridge University Press, Cambridge.

Stern, D.I., 2005. Beyond the Environmental Kuznets Curve: Diffusion of Sulfur-Emissions-Abating Technology. The Journal of Environment & Development 14, 101-124.

Stern, D.I., 2011. The role of energy in economic growth. Annals of the New York Academy of Sciences 1219, 26-51.

Stern, D.I., Kander, A., 2012. The Role of Energy in the Industrial Revolution and Modern Economic Growth. The Energy Journal, International Association for Energy Economics 0.

Stern, D.I., Kaufmann, R.K., 1996. Estimates of global anthropogenic methane emissions 1860-1993. Chemosphere 33, 159-176.

Tello, E., Ostos, J., 2011. Water consumption in Barcelona and its regional environmental imprint: a long-term history (1717–2008). Regional Environmental Change, 347-361.

Wrigley, E.A., 1988. Continuity, chance andchange.The Character of the Industrial Revolution in England. Cambridge University Press, Cambridge.

Yang, H., Wang, L., Zehnder, A.J.B., 2007.Water scarcity and food trade in the Southern and Eastern Mediterranean countries. Food Policy 32, 585-605.

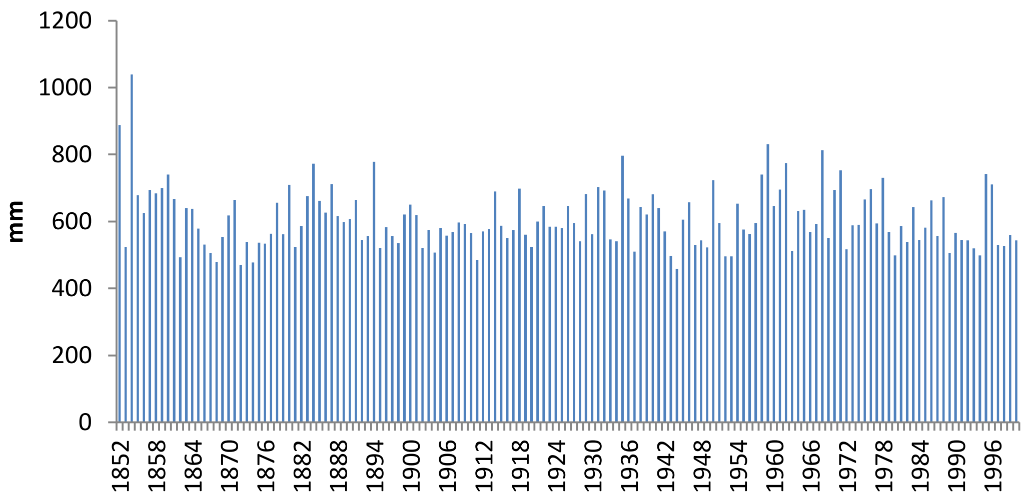
Appendix 1: Uncertainty

The data, taken from Mekonnen and Hoekstra (2011, 2012), provide information concerning the average volume of water required per crop, from 1996 to 2005. Although the main focus of this paper is to examine long-term trends in virtual water, an analysis of the impact of the assumption that evapotranspiration at the end of the twentiethcentury can be applicable to the ninetieth century, is now in order.

As stated earlier, Mekonnen and Hoekstra (2011, 2012) obtain water demand coefficients following Allen et al. (1998), who consider that evapotranspiration (crop water use) under non-optimal conditions depends on climatic parameters, crop characteristics, and management and environmental conditions. Whereas crop parameters are assumed to be static (Allen et al., 1998), climatic variables may have changed over time. Consequently, we have proceeded to examine time series for some of the variables for which long-term data are available.

Firstly, if we observe Figure 4, which offers data on average precipitation in Spain, and following Carreras (2005), it is possible to say that precipitation generally appears to be fairly stable from 1852 to the present day. However, due to the marked variability of these data, there is currently no clear evidence regarding trends in precipitation (Rodrigo and Barriendos, 2005; Pauling et al., 2006).

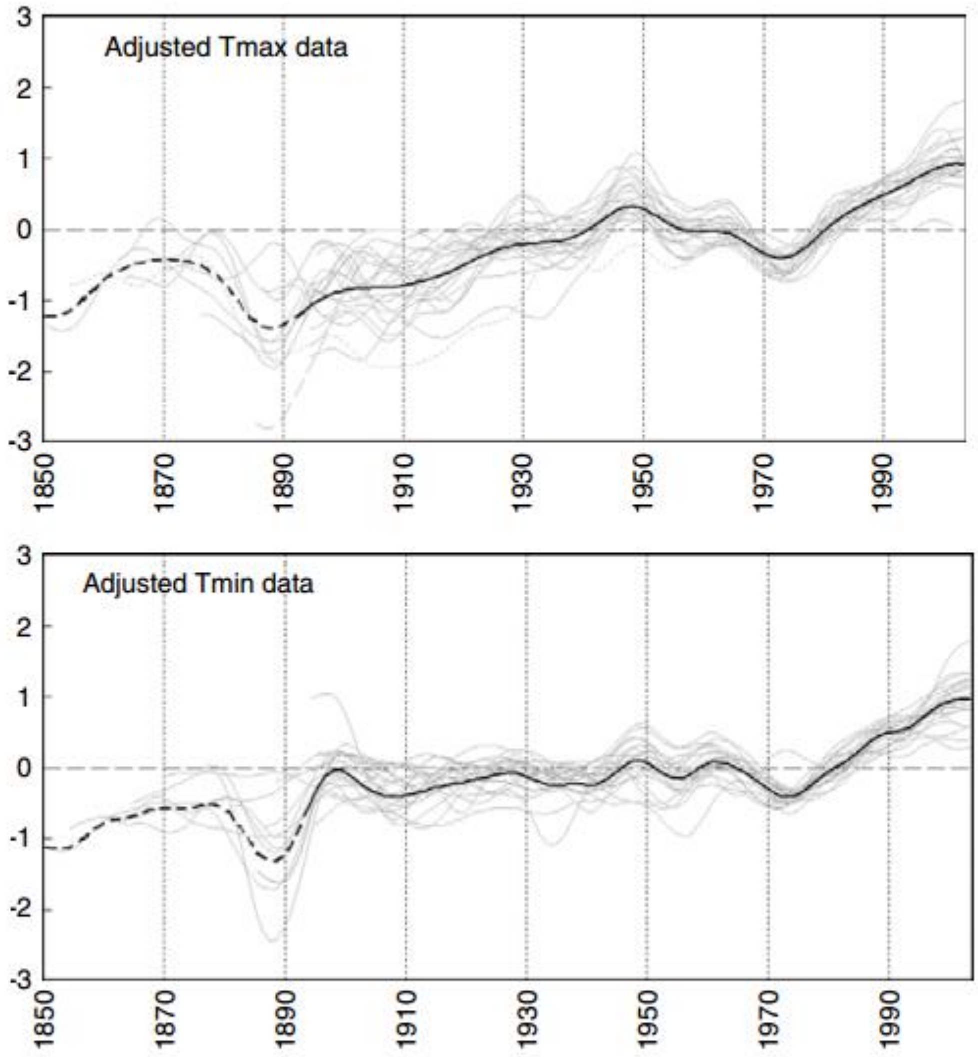
Figure 4: Average annual precipitations in Spain (mm)



Source: Authors' elaboration, from Carreras (2005).

By contrast, most researchers into climatic history are apparently in agreement concerning the rise in global temperatures (Guiotet al., 2010; Brunet et al., 2006), as illustrated in Figure 5, which displays the trajectory of adjusted annual variations (1850–2003) in daily maximum and minimum temperature records.

Figure 5: Adjusted annual variations (1850–2003) of daily maximum and minimum temperature

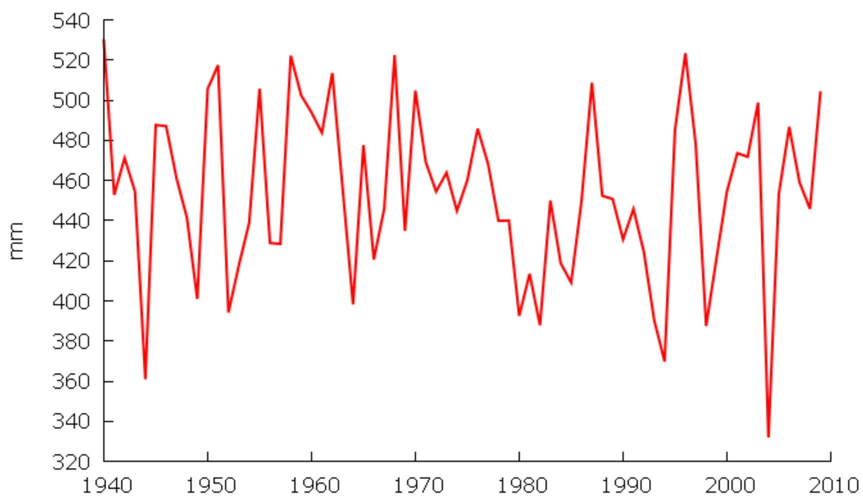


Source: Brunet et al. (2006)

While it is possible to discover many variables affecting crop water use in different ways, it is impossible to find a long-term series that helps us to determine their overall effect on evapotranspiration throughout the study period.

As a result, faced with the impossibility of exploiting an accurate reconstruction of crop water requirements, we sought an alternative time series dataset for long-term evapotranspiration in Spain. For the twentieth century, we discovered historical data for real and potential evapotranspiration for the period 1940-2010. According to MAGRAMA (2013), potential evapotranspiration (ETP), which is highly dependent on temperature, is that evapotranspiration produced with soil moisture and vegetation under optimal conditions. Its mean reaches 1,041 mm, showing its highest values in the south of Spain, the Ebro Valley, and the Canary Islands. In turn, real evapotranspiration (ETR) is that which actually takes place under existing conditions. In Spain, this reaches an average of 453.65 mm, notably below ETP because optimal soil humidity conditions are not fulfilled. Since ETR is the actual volume of water required by crops, we performed an econometric analysis of this time series to determine whether keeping its magnitude constant over time is justifiable. As a first step, we shall observe the time series graph, which appears to have no definite tendency and fluctuates around its mean. In other words, it appears to be stationary in the meanat first sight.

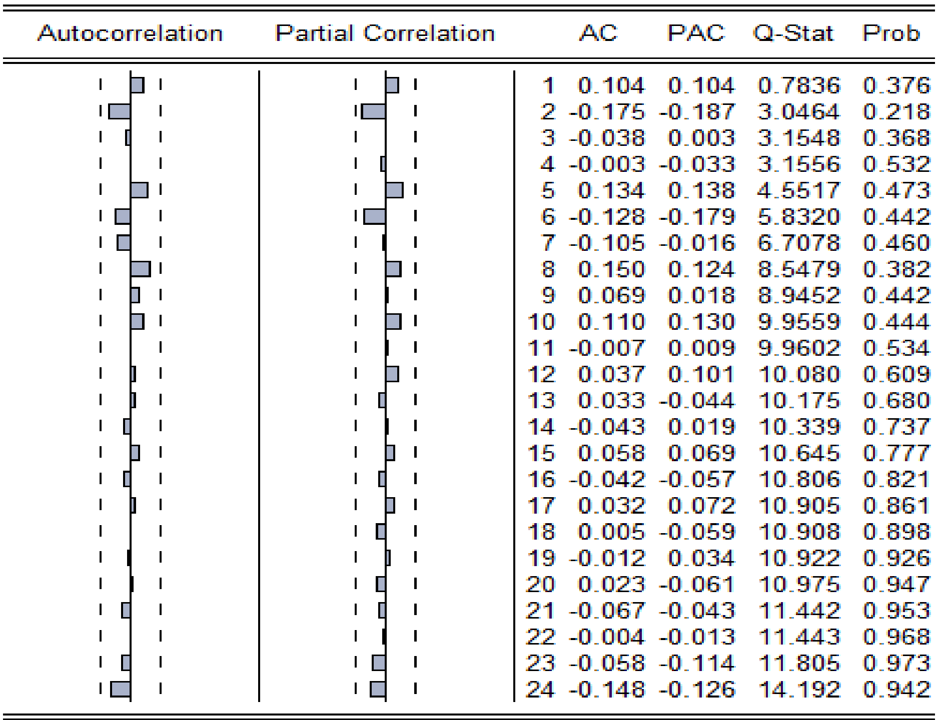
Figure 6: Real evapotranspiration in Spain (mm)



Source: MAGRAMA (2013)

It is also necessary to undertake a range-mean analysis to check whether the series is variance-stationary. We find that the slope of the range with respect to the mean equals -0.27, with a p-value of the test of p=0.77; this leads to the non-rejection of the null hypothesis of the slope=0, and the conclusion that the series is also variance-stationary. Moreover, if we observe the correlogram of real evapotranspiration, this also points to a stationary series. Finally, to gather hard evidence regarding the stationary character of real evapotranspiration we perform the KPSS test (Kwiatkowski-Phillips-Schmidt-Shin), which yields a statistic of 0.074, and thus the null hypothesis of stationarity at the 1% significance level is not rejected.

Figure 7: ETR correlogram



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.104	0.104	0.7836	0.376
		2	-0.175	-0.187	3.0464	0.218
		3	-0.038	0.003	3.1548	0.368
		4	-0.003	-0.033	3.1556	0.532
		5	0.134	0.138	4.5517	0.473
		6	-0.128	-0.179	5.8320	0.442
		7	-0.105	-0.016	6.7078	0.460
		8	0.150	0.124	8.5479	0.382
		9	0.069	0.018	8.9452	0.442
		10	0.110	0.130	9.9559	0.444
		11	-0.007	0.009	9.9602	0.534
		12	0.037	0.101	10.080	0.609
		13	0.033	-0.044	10.175	0.680
		14	-0.043	0.019	10.339	0.737
		15	0.058	0.069	10.645	0.777
		16	-0.042	-0.057	10.806	0.821
		17	0.032	0.072	10.905	0.861
		18	0.005	-0.059	10.908	0.898
		19	-0.012	0.034	10.922	0.926
		20	0.023	-0.061	10.975	0.947
		21	-0.067	-0.043	11.442	0.953
		22	-0.004	-0.013	11.443	0.968
		23	-0.058	-0.114	11.805	0.973
		24	-0.148	-0.126	14.192	0.942

Source: Authors' elaboration

In short, real evapotranspiration appears to be stationary in the long term, providing us with a certain degree of confidence in the hypothesis of constant water evapotranspiration during the period studied.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998.Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and drainagepaper 56.

Barciela, C., Giráldez, J., GEHR, López Ortiz, I., 2005. Sector agrario y pesca, in: Carreras, A., Tafunell, X. (Eds.), Estadísticas históricas de España I. Fundación BBVA, Bilbao, pp. 245–260.

Brunet, M., Saladié, O., Sigró, J., Aguilar, E., Lopez, D., Jones, P., Lister, D., Moberg, A., Walther, A., Almarza, C., 2006. The development of a new dataset of Spanish daily adjusted temperature series (SDATS) (1850-2003).International Journal of Climatology 26, 1777-1802.

Carreras, A., 2005. Clima, in: Carreras, A., Tafunell, X. (Eds.), Estadísticas históricas de España I Fundación BBVA, Bilbao, pp. 245–260.

Guiot, J., Corona, C., Brewer, S., Chalie, F., Daux, V., Edouard, J.L., Girardclos, O., Guibal, F., Lambert, G., Masson-Delmotte, V., Pichard, G., Servonnat, J., Swingedouw, D., Thomas, A., Yiou, P., 2010. Growing season temperatures in Europe and climate forcings over the past 1400 years.PloSOne 2010, 1-19.

MAGRAMA, 2013. Sistema de indicadores del agua. http://servicios2.marm.es/sia/indicadores/mapa_indic.jsp [Lastaccessed: April 2013]

Mekonnen, M., Hoekstra, A., 2012.A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems 15, 401-415.

Mekonnen, M.M., Hoekstra, A.Y., 2011. The green, blue and grey water footprint of crops and derived crop products.Hydrol. Earth Syst. Sci. 15, 1577-1600.

Pauling, A., Luterbacher, J., Casty, C., Wanner, H., 2006. Five hundred years of gridded high-resolution precipitation reconstructions over Europe and the connection to large-scale circulation. Climate Dynamics 26, 387-405.

Rodrigo, F.S., Barriendos, M., 2008.Reconstruction of seasonal and annual rainfall variability in the Iberian peninsula (16th-20th centuries) from documentary data.Global and planetary change 63, 243-257.

Appendix 2: Production estimates

To estimate the volume of water for Spanish production it was necessary to get Spanish agrarian production for 1860, 1900, 1930, 1962 and 2008. On the whole, for the period 1860-1930 Spanish agrarian production data come from "Estadísticas Históricas de la Producción Agraria Española, 1859-1935" (GEHR, 1991).To reduce data volatility, we employed triennial production averages whenever possible. Crops for livestock feed are not considered, to avoid double counting.

Since "Estadísticas Históricas de la Producción Agraria Española", 1859-1935 do not provide data for most products in 1860, we used alternative sources. Specifically, data for physical production of wheat, rye, barley, oats, corn, rice, chickpeas, broad beans, beans, potatoes, sweet potatoes, wine, olive oil, flax, hemp, almonds, chestnuts, oranges, lemons, raisins, figs and olives have been taken from Bringas (2013), whose information is based on Navarro Faulo (1882). Data on sugar cane and sugar beet production were taken from Martín Rodriguez(1994).The remaining agricultural products were obtained by assuming that per capita production in 1860 and 1900 were the same. Thus, Spanish production minus exports in 1900 was divided by population in that year, obtaining the non-exported per capita production. Subsequently, we multiplied the former coefficient by the number of inhabitants in 1860 and, where information is available; we added exports in 1860 from foreign trade statistics for Spain. The next step involved estimating livestock production. Data on animal numbers were taken from GEHR (1991), which collects data from the "Censo de Ganadería" (Livestock Census) of 1865. We used these to estimate meat production, keeping in mind the age and sex of different livestock species, the average life of animals before slaughter, and the meat obtained from each animal, adult and young. To calculate the coefficients of conversion we used the livestock census of 1932 and the data for animals in the slaughterhouse of Zaragoza between 1870 and 1935 (Pinilla, 1995b). We took the data for milk from Hernández Adell (2012). The problem with production data for crops in 1860 stems from a serious underestimation, as Bringas (2013) points out. Nevertheless the livestock production data appear to be correct or, at worst, somewhat overestimated. In order to verify the quality of the data, we compared the differences in the monetary value of production in our calculations for 1860 and 1900. The result is disproportionate growth if compared with the growth of gross agricultural value added between 1860 and 1900, supplied by Prados de la Escosura (2003). To correct our estimate from 1860, and following the principal analyses (GEHR, 1978 and 1979; Bringas, 2013), we assumed that there exists a serious problem of the underestimation of crop production for 1860, while the data for animal production were correct. To resolve this problem, we have re-scaled crop production to its corresponding value assuming that the data from Prados de la Escosura are reliable.

For those goods for which we have no information for 1900, we assumed that their production followed a similar pattern to the nearest similar crop for which data were available. The following table provides information about the crops for which we have no data, the coefficients used, and the reference product or group of products used to obtain them. The main source is also given.

Table 3: Products with no data in 1900 and crops used to estimate their production

Data unavailable for	Similar crop
Grapes	production of wine
Raisins	production of wine
Olives	production of olive oil
Source: GEHR (1987)	
Sweet potatoes	potatoes
Walnuts	almonds
Dates	figs
Source: GEHR (1991)	
Tomatoes	horticultural products
Peppers	horticultural products
Artichokes	horticultural products
Asparagus	horticultural products
Green beans	horticultural products
Melons	horticultural products
Water melons	horticultural products
Aniseed	horticultural products
Source: GEHR (1983), Gallego (1986), Pinilla (1992)	

For livestock production data in 1900 we obtained the number of animals of each species from the livestock census for 1910 (based on GEHR (1978, 1979)). We then proceeded in a similar way for 1860 to estimate meat production. Data for milk are from Hernández Adell (2012), and the numbers for eggs come from the official data for 1908.

References

Bringas, M.A., 2013. Navarro Faulo y la estadística de los productos vegetales de 1859, mimeo.

Gallego Martínez, D., 1986. La producción agraria de Álava, Navarra y La Rioja desde mediados del siglo XIX a 1935. Universidad Complutense de Madrid

GEHR, 1978. Contribución al análisis histórico de la ganadería española, 1865-1929. Agricultura y Sociedad 8, 129-182.

GEHR, 1979. Contribución al análisis histórico de la ganadería española, 1865-1929. Agricultura y Sociedad 10, 105-169.

GEHR, 1983. Notas sobre la producción agraria española, 1891-1931. Revista de Historia Económica 1, 185-252.

GEHR, 1987. Un índice de la producción agraria española, 1891-1935. Hacienda Pública Española 108-109, 411-422.

GEHR, 1991. Estadísticas históricas de la producción agraria española, 1859-1935. Ministerio de Agricultura, Pesca y Alimentación. Madrid.

Hernández Adell, I., 2012. La difusión de un nuevo alimento: producción y consumo de leche en España, 1865-1936, Tesis de Doctorado, Facultad d'Economia i Empresa, Universitat Autónoma de Barcelona.

Jiménez Blanco, J.I., 1986. Introduction, in: Garrabou, R., Barciela, C., Jiménez Blanco, J.I. (Eds.), Historia agraria de la España contemporánea. 3. El fin de la agricultura tradicional (1900-1960). Editorial Crítica, Barcelona.

Martín-Retortillo, M., Pinilla, V., 2013. Patterns and causes of growth of European agricultural production, 1950-2005.Documentos de Trabajo (DT-AEHE) 1302.

Martín Rodríguez, M., 1994. Del trapiche a la fábrica de azúcar, 1779-1904, in: Nadal, J., Catalán, J. (Eds.), La cara oculta de la industrialización española: la modernización de los sectores no líderes. Alianza Editorial, Madrid, pp. 43-98.

Navarro Faulo, J., 1882. Geografía militar y económica de la península ibérica y colonias de España y Portugal. Madrid.

Pinilla, V., 1992. La producción agraria en Aragón (1850-1935). Revista de Historia Económica 10, 399-429.

Pinilla, V., 1995 Entre la inercia y el cambio. El sector agrario aragonés, 1850-1935. Ministerio de Agricultura, Madrid.

Prados de la Escosura, L., 2003. El progreso económico de España (1850-2000). Fundación BBVA, Bilbao.